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Independent information modules—a powerful approach for life cycle management

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Abstract

Background, aim, and scope The term “information module” has been initially introduced by ISO 14025 (ISO 14025 2006) which specifies Type III environmental declarations. It comprises a set of predetermined parameters (PDPs) assigned to a process. Such a process can be part of a product system, i.e., a unit process or a combination of unit processes as, e.g., the production processes of a company. Independent information modules (IIMs) of processes within a system are modeled in a way that the predetermined parameters of the information modules related to these processes are identical and sufficiently independent so they can be added up to the predetermined parameters of such a system, typically after multiplication with specific factors based on the reference flow of the system.

Materials and methods This paper shows how IIMs can be used as powerful approach in life cycle management and how operations, goods, and services of a company can be modeled efficiently with the help of IIMs. To define environmental objectives of their operations, organizations typically assess their foreground processes but do not apply system expansion for each of the foreground processes to include background processes. With the help of IIMs, background processes can be easily included, and the PDPs, therefore, also include both direct and indirect elementary flows, i.e., emissions and resources. In a “plant ecobalance” the PDPs of the different (foreground and background) processes of an organization can be determined and added up. This provides each process owner with important information about the environmental aspects which he or she can control and shows options for setting and implementing environmental objectives. For specific purposes, the number of PDPs can be restricted or even limited to one parameter, e.g., the carbon footprint. This paper illustrates the method with one example of the aluminum industry (carbon footprint of an automotive bumper beam) and shows how PDPs of product systems can be built up from IIMs which represent the different stages of a life cycle; how such results can show the influence of these stages in a transparent way, as required as a part of the life cycle interpretation phase.

Results and discussion Life cycle assessments (LCAs) based on IIMs follow the principles and requirements of ISO 14040 (2006) and ISO 14044 (2006), as applicable. However, as a specific approach of life cycle management, they can obtain the required information with less effort than “conventional” LCAs where, following the guidance of ISO 14044, indicator results are calculated after the inventory data have been aggregated for the whole product system. Future efforts in ISO standardization should strengthen the role of LCA as a tool of environmental management.

Keywords Carbon footprint · Independent information module (IIM) · Information module · Life cycle management (LCM) · Modular LCA · Plant-ecobalance · Predetermined parameter (PDP) · Site-oriented environmental management

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1 Background, aim, and scope

The term "information module" has been initially introduced by ISO 14025 (2006) which specifies Type III environmental product declarations. Type III environmental product declarations (EPDs) are claims which indicate the environmental aspects of products, i.e., goods or services. Such declarations may be based on data which describe the whole life cycle of a product or on data which describe specific parts of a life cycle (information modules). The creation of EPDs follows a procedure as specified in ISO 14025 including:

– the formulation of product category rules, a document, approved by a panel, which defines the goal and scope for a specific product category;
– the selection of predetermined parameters (PDPs) and other environmental information related to one or more products within the product category;
– the formulation and validation of the declaration.

Modularity is one principle of a Type III EPD (with the term "information module" occurring 44 times in the document). For the purpose of a Type III EPD, the information module is defined as a compilation of data covering a unit process or a combination of unit processes that are part of the life cycle of a product.

In Annex B of ISO 14025, by use of the example of a glass bottle, it is shown how an information module referring to the life cycle of a component of a product can be obtained by combining information modules which refer to different life cycle stages. It is also shown how PDPs based on the life cycle of the product can be obtained by combining the PDPs of the different components and the assembling processes. Each information module can be, but need not be, the result of a Type III EPD.

A similar example can be found for the case of a Type III EPD of a building product (aluminium window) in ISO 21930 (2007).

The Type III EPD procedure invites sectoral associations to develop information modules based on environmental data of those processes where the industry sector has specific access and know-how. By aggregating the data of verified EPDs and those of the missing information modules (from data providers), a full life cycle assessment (LCA) with an excellent data quality can be obtained.

2 From information modules to independent information modules

An information module represents a process. Such a process can be a single unit process or comprise a system of unit processes. It can be part of the operations of an industrial plant (or covering all operations), or it can be part of a product system, e.g., a stage of a life cycle.

PDPs are parameters which are assigned to information modules intended to quantify environmental aspects.

Ideally, PDPs include parameters which quantify all significant environmental aspects of the system under study. Not only can such parameters be indicator results related to impact categories but also elementary flow data and technical parameters can be used, as appropriate.

In order to describe the environmental performance of a system, a comprehensive set of parameters (often ten to 15) should be used. For aspects, where quantification is not appropriate or not yet sufficiently possible in a scientifically valid manner (e.g., impacts from landfilling of waste), qualitative or semiquantitative information should be added.

Independent information modules (IIMs) of the processes in a system are information modules:

– where the PDPs are the same for all of these processes;
– where each process is independent from the others and includes all relevant background processes (and usually only has one input and one output, which represent the "connectors" to the other IIMs).

This means that the PDPs of the IIMs of a system, e.g., the processes of a plant or those of a product system, can be arranged in a table and added up, typically after multiplication with a factor based on the reference flow.

Modern databases, e.g., GaBi or SimaPro offer input and output data for a large number of processes, both in the form of elementary flows and in the form of indicator results and other parameters. It has been experienced that IIMs can be easily modeled and extracted from such databases or purchased from the data provider.

2.1 Selection of predetermined parameters

The IIMs are characterized by PDPs. Typically, they include clearly defined indicator results, related to the following impact categories:

– depletion of energy resources [MJ]—ISO/TR 14047 (ISO/TR 14047 2003);
– depletion of abiotic resources [kg Sb equiv]—CML 2001;
– climate change (GWP) [kg CO_2 equiv]—latest version of IPCC;
– destruction of atmospheric ozone (ODP) [kg R11 equiv]—latest version of WHO;
– acidification (AP) [kg SO_2 equiv]—CML 2001;
– eutrophication (NP) [kg PO_4 equiv]—CML 2001;
– photochemical ozone creation (POCP) [kg ethen equiv]—CML 2001.

In order to determine these indicator results for a given process, the inputs and outputs of an IIM have to be calculated as elementary flows and the classification and characterization steps of life cycle impact assessment have to be carried out for the elementary flows of the IIM, according to ISO 14044 (2006).

Additionally, the technical nonelementary flows (see also Rebitzer 2005) that represent impacts not yet well covered by LCIA methods, e.g.:

- renewable energy resources (in mega joule);
- different types of waste (in kilogram, after treatment);
- water consumption (in cubic meter)

can be included into the list of PDPs as they occur as inputs or outputs of the process under consideration. These are flows or other environmental interventions for which no widely accepted impact categories and corresponding characterization factors exist (yet). Therefore, the inclusion of such technical indicators may be the more pragmatic approach.

Experience has shown that it is difficult to communicate too many PDPs to interested parties within or outside an organization. Therefore, in addition to the parameters as defined above, a restricted list of PDPs can be defined. As an example, Alcan Engineered Products and Alcan Packaging use five parameters for internal application and communication, i.e.:

- nonrenewable primary energy consumption;
- greenhouse gas emissions;
- Eco-Indicator 99, excluding greenhouse gas emissions and nonrenewable primary energy consumption (to check other impacts, but avoiding double counting);
- fresh water consumption;
- waste parameter, where the different types of waste are added up by use of simple characterization factors (see Rebitzer 2005).

From these five parameters, greenhouse gas emissions, upon special request, can be selected and reported as "carbon footprint" of the relevant process, life cycle stage or product system (see also Section 4).

2.2 Modeling independent information modules (based on Rebitzer 2005)

2.2.1 Foreground unit processes

Input and starting point to modeling independent information modules are the collected data on the elementary flows of the "foreground unit processes." The foreground processes are those processes that are "related specifically to the product system at stake" while "background data are not specifically related to the product system and may consist of averages or ranges" (Udo de Haes et al. 1994). Others coin the foreground processes "main process chain" (e.g., Fleischer and Hake (2002)) or "major unit processes" (e.g., Guinée et al. (2002)) or use other similar terms. One can conclude that the foreground unit processes are those processes which are in the core of the analysis, for which data have to be specifically collected and analyzed and which interactions are of interest for the LCA. Often, many of these foreground processes are under the direct influence of the organization conducting the LCA, which is of high importance with regard to influencing environmental impacts and introducing improvements. Specifically, for industrial applications the internal production and recycling processes are usually foreground processes.

2.2.2 Extension of foreground unit processes with background data and substitution of losses

In this modeling step, the data of the foreground processes are each extended to include (a) the associated background data and (b) the substitution of material losses, the latter where relevant and appropriate.

1. Generally, each foreground unit process is connected to background data such as life cycle inventories for generic energy generation, supply of ancillaries, or generic recycling and disposal processes. These data are usually obtained from publicly available or commercial data bases that are based on industry averages and generic models. This extension with background data is prepared per foreground process prior to the modeling of the initial or complete product system.
2. For transformation processes and product finishing operations, an extension to include the primary production needed to substitute material losses of the foreground process completes this step. These substitutions represent the environmental impact related to the materials that are not transformed into the desired output of the processes (losses [%]=100% – yield [%]). As a consequence many processes can be modeled in a way that the value of the mass flow that is linked to the preceding foreground process is identical to the mass flow of the succeeding process (e.g., 1 kg output as reference flow and 1 kg linked input flow). However, there are exceptions to this such as processes where the main input materials are raw materials in the form of elementary flows (minerals or fossil resources from the ground) or where the primary production that replaces losses is represented by the foreground process itself (recursive model).

Results are extended unit processes, with defined input and output system flows (one of them being the reference flow, depending if it is a production or use, or an end-of-life

process). These input and output system flows resemble the links to the other foreground processes, up- and downstream, respectively. After the extension, all other system flows and the associated processes are part of the module. Figure 1 illustrates such a module, with the foreground process and the extensions.

2.2.3 Determination of PDPs

As the next step, the inputs and outputs of the independent LCI module are transformed into PDPs. For this purpose, the resulting elementary flows are assigned to the predetermined impact categories, followed by the calculation of indicator results according to the life cycle impact assessment framework of ISO 14040. Those PDPs which are no indicator results can be directly collected from the flows without further transformation. Additional environmentally relevant qualitative or quantitative information (e.g. technical nonelementary flows as described in Section 2.1), as appropriate, has to be documented for each module as well.

2.2.4 Connection of IIM to model the product system

The model of the complete product system is obtained by connecting and combining the IIMs to include all relevant processes and life cycle phases related to the functional unit analyzed. This modeling step is similar to the normal modeling of the product system in the life cycle inventory analysis phase. However, in this approach, it is not the elementary flows that are aggregated but the resulting PDPs. Since this has to consider only the predetermined set of indicators and not a huge array of material and energy flows and other interventions, this combination is simpler than in a conventional LCA, though leading to identical results. In addition, for most transformation processes, the combination via the reference flows of the independent LCA modules does not need to consider process yields if the substitution of the losses is fully integrated into the independent LCI module (see Section 2.2.2).

Special care related to the choice of system boundaries, energy models, etc. has to be taken if this modeling procedure is used to combine IIMs of different organizations. Only if consistent IIMs with regard to modeling choices and system boundaries are used can they be combined. For this, Product Category Rules (see ISO 14025 2006) or a similar procedure may be used.

In order to create models that are easily usable also by non-LCA experts and without specialized software, the product system is implemented in the form of spreadsheet models which contain the PDPs of the required LCA modules and the interconnections. Parameters that should be variable due to their relevance with regard to assumptions, "what if" scenarios (Weidema et al. 2004), decision relevance, or that relate to different options (e.g., comparisons to competing products) are introduced in a flexible way. This ensures that the influence of these parameters on the overall result of assessing one single product or for internal comparisons between products and alternative life cycles can be easily analyzed. Simple variations of the product can be assessed without complex changes to the model.

Of specific importance for industrial applications, e.g., for the product development process, are the variable parameters in regards to decision relevance. Decision relevant are those parameters which can be influenced by the industrial (or other) actor. For product development, for instance, these might be technical parameters of the product design that can be varied. This means that the LCA expert

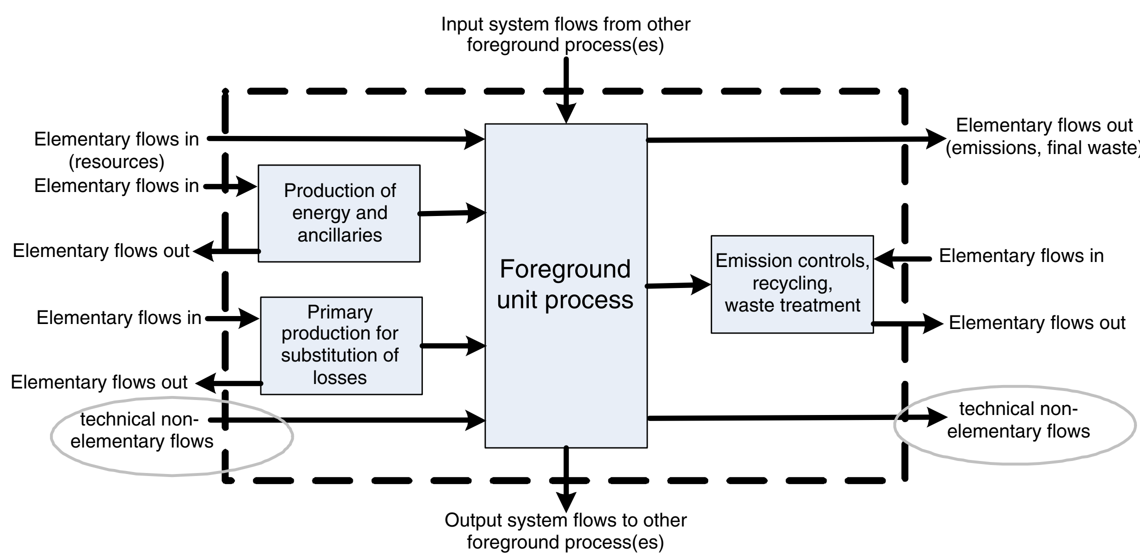


Fig. 1 Independent information module (based on Rebitzer 2005)

setting up the system has to identify the specific requirements of the user(s) of the model who will later work with the system. The latter is essential, so that the model is specifically targeted at the user and can give direct decision support, without the need to involve the LCA expert at all times. The LCA expert is only required if more severe changes to the model, such as the establishment of new parameters, the adding of new independent LCA modules, or other general modifications are necessary. This reduces the effort for the internal LCA expert to providing the tools, associated training, and support for very specific or complex questions and interpretation needs.

The aforementioned procedure for modeling the complete product system model also enables straightforward dominance and sensitivity analyses with regard to the variable parameters, which is important for finding key environmental aspects and assumptions that, in turn, can be used again as guiding factors for product design, process improvements, etc.

2.3 The modular LCA in the light of the ISO standards on LCA

As shown in Fig. 2, a modular LCA consists of the same steps as an LCA according to the guidance given in ISO 14044. However, in the modular LCA, the first steps of the impact assessment, classification, and characterization are already done on the process level after the inclusion of the background processes, whereas the "conventional LCA" performs these LCIA steps on the systems level, after aggregation of the relevant inventory data.

ISO 14044 states that such an interchange is permitted, provided that the resulting data are not different. It has been shown by Rebitzer (2005) that such an interchange has no influence on the results of an LCA. This means that the modular LCA, based on IIMs, is generally in line with ISO 14044.

The identification of significant environmental issues is one part of the interpretation phase of the life cycle assessment. According to ISO 14044, the resulting data of the LCA have to be restructured in order to determine, e.g., significant contributions from the different life cycle stages, such as individual unit processes or groups of processes. The modular LCA supplies the matrix of PDPs of the different life cycle stages of a product as an intermediate step; see Table 1 as one example. Therefore, no restructuring of the data is necessary in order to determine the significant environmental issues; interpretation is facilitated.

As shown in Section 1, information modules and PDPs have been introduced by ISO 14025 as building blocks for LCAs. However, these terms are used neither in ISO 14040 nor in ISO 14044. Further alignment between these ISO standards is necessary.

3 Application of IIMs in site-oriented environmental management

As outlined above, IIMs can be used straightforward to model product systems in an efficient way. Some examples relating to the impact category of climate change are given in Section 4 below. However, IIMs are also extremely

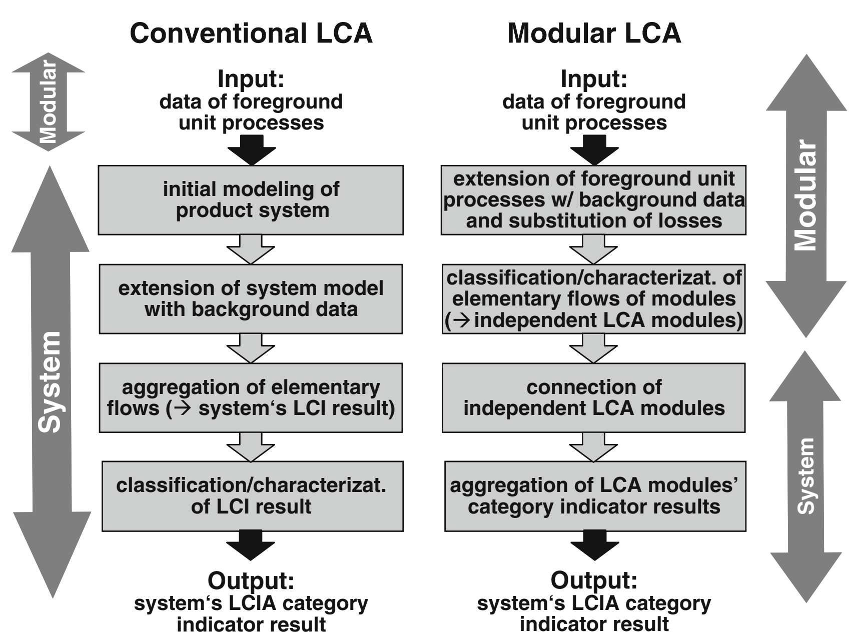


Fig. 2 Conventional and modular LCA (based on Rebitzer 2005)

Table 1 Matrix of PDPs of the different life cycle stages of a metal product

Life cycle stage	Predetermined parameter (PDP) per reference flow				
Fabrication	X11	X12	X13	X14	X15…X1n
Finishing	X21	X22	X23	X24	X25…X2n
Use	X31	X32	X33	X34	X35…X3n
Recovery	X41	X42	X43	X44	X45…X4n
Remelting	X51	X52	X53	X54	X55…X5n
Total	S1	S2	S3	S4	S5…Sn

useful in site-oriented environmental management. This application is elaborated in the following.

3.1 Requirements of site-oriented environmental management (ISO 14001) with relation to IIMs

ISO 14001 requires that the organization shall establish, implement, and maintain (a) procedure(s) (see ISO 14001, 4.3.1):

1. to identify the environmental aspects of its activities, products, and services within the defined scope of the environmental management system that it can control and those that it can influence taking into account planned or new developments, new or modified activities, products, and services and
2. to determine those aspects that have or can have significant impact(s) on the environment (i.e., significant environmental aspects).

The organization shall document this information and keep it up to date. The organization shall ensure that the significant environmental aspects are taken into account in establishing, implementing, and maintaining its environmental management system.

Usually, the environmental manager of a company has some experience in the collection of environmental data related to the whole plant, i.e.:

– emissions to air and water generated by the processes within the fences of the site;
– energy and water consumption; and
– waste generation,

since such data often have to be reported to local authorities. Typically, such data are collected for the whole plant (black box).

However, this is often not sufficient for an environmental management system based on ISO 14001, because the environmental aspects which have to be identified according to this standard are defined as elements of an organization's activities, products, or services that can interact with the environment. In order to fulfill this requirement, at minimum, the environmental data have to be determined individually for the different processes of the plant in order to find out to which extent these processes interact with the environment.

This means that environmental data have to be collected process by process, and the data of shared process such as maintenance or administration have to be allocated to the different processes according to well-defined rules. The result of a process specific data collection campaign is a list of data for each of the processes.

However, only data on emissions to air and water can be considered as elementary flows, i.e., as outputs which directly interact with the environment without subsequent human transformation. On the input side, in addition to water consumption from own wells or taken out of a river or lake, data can only be considered as elementary flows if the plant is involved in mining activities or if it has own oil or gas wells. Such data are termed "direct elementary flows."

Using these collected datasets, with the help of data providers, the processes of the plant can be modeled as IIMs after inclusion of the background processes, as shown in Section 2.2. The elementary flows related to the background processes are termed "indirect elementary flows." They are generated by processes outside the site but caused by the operations of the site, e.g., the generation of the emissions of a power plant caused by electricity consumption of a process. The resulting set of PDPs should cover all types of parameters which are of environmental relevance.

The list of processes modeled as IIMs can be considered as the list of environmental aspects. The PDPs of these IIMs are a quantitative basis to determine those processes which are responsible for significant environmental aspects (significant IIMs).

3.2 The use of IIMs for the determination of site-oriented environmental objectives and targets

ISO 14001 requires from an organization to take into account its significant environmental aspects when establishing and reviewing its objectives and targets. If these aspects are modeled as IIMs, then possible improvements of the input and the output data of these IIMs can be formulated, including:

– reduction of emissions and waste;
– reduction of energy consumption;
– reduction of production scrap or material losses.

Any proposed improvement can be subjected to a scenario, where the PDPs of the improved process (proposal) are compared with the PDPs of the baseline, i.e., the process as it is. The difference of these PDPs can be considered as a quantitative measure of the proposed improvement.

Such scenario analyses can be performed for all of the proposed improvements related to the different environmental aspects. Based on the quantitative results, a priority list of possible improvements can be established to be used as a basis of the determination of the environmental objective and targets.

An analysis where the PDPs of the operations of a plant are determined and a list of quantitative data related to different environmental improvements is elaborated can be termed "plant eco-balance."

3.3 The use of IIMs for covering the product view in site-oriented environmental management

An effective site-oriented environmental management system requires that the organization, when determining the significant environmental aspects, does not only consider the operations within their fences (and the related background processes) but also the products (goods and services) it produces (as also prescribed in ISO 14001).

The environmental aspects of the operations of this plant, related to all of its products, are covered by the plant eco-balance.

The necessary steps to also consider the environmental aspects of the generated products are the following:

- define all stages of the life cycle of the products;
- identify those stages where the organization can influence or control the PDPs and model them as IIMs, whether the related processes are within or outside of the organization;
- develop the relevant improvement scenarios;
- calculate the relevant improvement PDPs, i.e., PDP (case) minus PDP (baseline).

As a result, the organization can have one common list of environmental objectives together with the calculated improvement PDPs for both the improvements based on the plant eco-balance and the improvements based on product LCAs.

4 Carbon footprints of products based on IIMs

4.1 Carbon footprints, IIMs, and LCA

Increasingly suppliers are faced with customer requests asking for the "carbon footprint" of the offered products in order to determine how far these contribute to climate change impacts. In such a case, the sales of products showing a significantly higher carbon footprint than alternative products might be affected.

In this context, it is important to note that while the term carbon footprint is relatively new, methods to determine the climate change impacts of goods and services exist for several years, such as the calculation of the LCIA category indicator result of the impact category "climate change" via impact assessment according to ISO 14040. The carbon footprint of a product is then defined as the sum of the greenhouse gas emissions of all processes relating to the life cycle of the product.

As already mentioned in Section 2.1, the carbon footprint can be considered as one specific PDP which can be assigned to each of the stages of a life cycle. If the system is modeled with the help of IIMs, then the carbon footprint parameters of each stage of the life cycle can be easily added up, taking into account the reference flow of the product system, in order to obtain the carbon footprint of the product.

In many cases, carbon footprint studies cover the energy aspects and other greenhouse gas-related impacts of a process or a product quite well. However, compared with an LCA study, such studies do not take into account environmental impact categories other than climate change and therefore can give a distorted picture of the environmental performance of a product or a service. Statements and claims based on carbon footprint studies can be easily misunderstood and neglect tradeoffs.

However, in spite of such shortcomings and tradeoffs, the carbon footprint can demonstrate the importance of environmental objectives of an organization related to stages of the product life cycles that occur outside its fences. This will be further illustrated in the following section with an example from the aluminum industry.

Fig. 3 Aluminum bumper beams

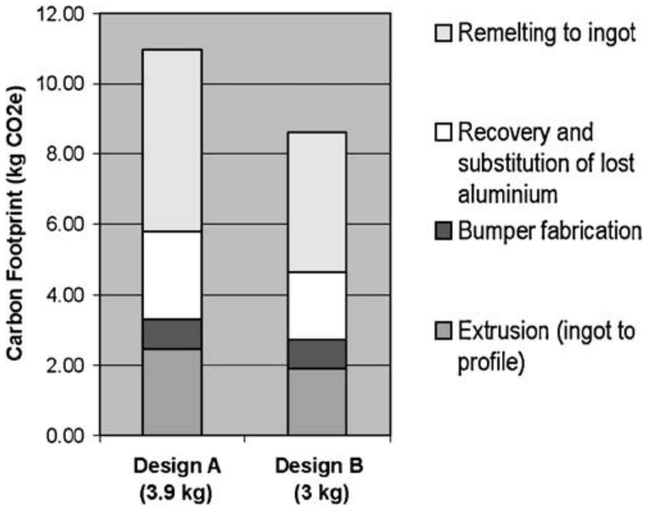


Fig. 4 Carbon footprint values of different IIMs without use stage

4.2 Carbon footprint of aluminum bumper beams

Aluminum bumper beams (Fig. 3) are more and more used as elements to absorb crash energy of cars. They are produced from extruded profiles with specifically designed cross-sections. Alloys and tempers with a high tensile strength and a high elongation at a high deformation rate are required for this product.

In this case study, a company has designed and produced bumper beams for a large series of a subcompact car for several years. As one environmental objective, it was decided to develop a new bumper beam for the same car (class) with the same crash absorption energy properties but with lower mass.

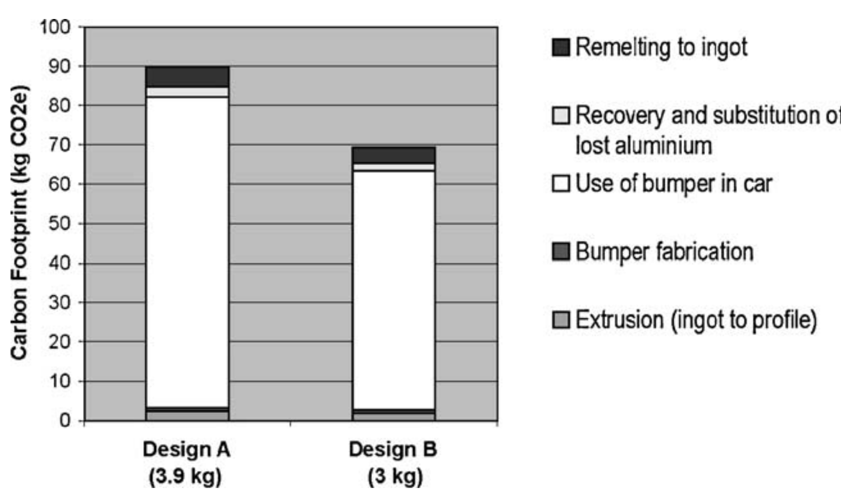
As a result, the mass of the bumper beam could be reduced from 3.9 to 3.0 kg by improved alloys and tempers and an improved design of the cross-section.

Figure 4 shows the carbon footprint values of the different IIMs of the life cycle of both the improved bumper beam (design B) and the baseline bumper beam (design A), excluding the use stage. It can be shown that the carbon footprint of the new design B is about 2.5 kg CO_2e lower than the value of the baseline. Of this, about 0.5 kg CO_2e per bumper beam are saved in the production stage. Assuming an identical recycling rate, however, the lower mass of the improved product also leads to lower absolute material losses for collection and in the recycling processes, delivering the other 2.0 kg of savings

However, if the carbon footprint of the whole life cycle including the use stage is considered, then the difference is much higher (see Fig. 5). In this case, special care is necessary when the carbon footprint of the use stage is calculated. For this purpose, as a first step, the carbon footprint CF_{tot} of the total car with its mass M is calculated, which, as a second step has to be allocated to the different components of the car. For this step, the guidance given in ISO 14044, sub clause 4.3.4.2, is followed, i.e., the chosen allocation factor should reflect the way how inputs and outputs are changed by quantitative changes in the product performance. If the mass of the component is increased by 10%, then the fuel consumption dependent inputs and outputs of the use stage increase by $10\times(1-W)$%, where W is the percentage air friction; see (Helms and Lambrecht 2007). Therefore, $M\times(1-W)$ is considered as allocation factor for the component. This means that one part of the carbon footprint, namely $CF_{tot}\times(1-W)$, is allocated to the masses so the different components, whereas the other part, $CF_{tot}\times W$, is allocated to the shape of the car (for further background on this allocation method and the resulting impacts for different masses of equivalent components, see Helms and Lambrecht 2007).

The difference between the design A and design B in Fig. 5 is 21 kg CO_2e per bumper. Assuming two bumpers per car and assuming that the new car series comprises 2 Mio. vehicles, to be built within 6 years, then the total savings are 84,000 tonnes, much more than the company can save by only considering its own operations.

Fig. 5 Carbon footprint values of different IIMs with use stage included



Moreover, the experiences of the new design can be used for the bumpers of further car series.

5 Conclusions

One can conclude that the main difference of the procedure using IIMs compared to the conventional LCA procedure is characterized by the fact that the impact assessment is performed per extended foreground unit process, before the modeling of the complete product system. As a result, the modular characteristics are not limited to the inventory data of the single unit processes as in a conventional approach but carried further. This further reach of the modular characteristics and, thus, the creation of reusable elements that integrate more elements of the complete LCA methodology can be seen as a clear advantage in regards to an efficient application of LCA. While the application efficiency is enhanced, the required granularity for decision making that aims at the foreground processes, is retained. This is a clear distinction to the use of fully aggregated cradle-to-gate data, where a later distinction between the different foreground processes is not possible anymore.

With this approach, synergies of using independent LCA modules for both product-oriented as well as site-oriented environmental management can be exploited, which is particularly interesting due to the widespread implementation of site-oriented systems. Additionally, the effort is minimized and simple models also to be used by the non-LCA expert can be easily assembled, facilitating the regular use of LCA for different purposes. In addition, the compact set of predetermined indicators can be easily communicated to different functions and decision makers within a company. Other possible uses not mentioned in this article concern the employment of IIMs for EPDs, since these resemble the so-called information modules needed for an EPD (ISO 14025 2006). This means that also customer inquiries in regards to the environmental performance of products or components can be answered based on the approach, without much additional effort.

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